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MAXIMUM SUSTAINABLE YIELD FROM THE ROBBEN FUR SEAL HERD*

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Introduction

There are three major breeding populations in the northern fur seals, *Callorhinus ursinus*, from the North Pacific. The largest population is from Pribilof Islands in the Bering Sea, and others are from Commander Islands in the Bering Sea and from Robben Island in the Okhotsk Sea. Since the Interim Convention of Conservation of North Pacific Fur Seals among Canada, Japan, USSR and USA entered into force in 1957, possible efforts have been directed to take effective measures towards achieving the maximum sustainable productivity of fur seal resources. The past papers written by Chapman (1961 and 1964) and Nagasaki (1961) on the maximum productivity on fur seals have been related only to the breeding population of Pribilof Islands, because the density dependent factors had a great effect on the level-off of the population early in the 1950's and hence estimates of maximum productivity became possible. The situation of population level was different among three stocks. Although the Robben seal herd has continued to increase in number as the result of conservation, it seems recently that its population level exceeds the maximum sustainable yield and comes in a stage of level-off.

With regard to intermixture of seals on the breeding islands, North Pacific Fur Seal Commission Report on Investigations from 1964 to 1966 (1969) states that the intermixture of fur seals of Commander and Pribilof origin on Robben Island is at a fairly low level. The rate of intermixture estimated by using the tag recovery rate shows that most of males of ages 3 and 4 on Robben Island is composed of native seals. According to the calculation from 1958 through 1963 data, native seals occupies 93.3—99.7% of males at Robben Island, while the seals from Commander Islands account for 0.3—1.9% and the seals from Pribilof Islands for 1.3—5.0% at that Island. This implies that the Robben population is almost independent from the Commander and the Pribilof population. From data of tag recovery observed in seals taken pelagically in the Sea of Japan, the report also suggests that the Sea of Japan is a main wintering area for the fur seals born at Robben Island.

Several biological parameters should be examined to reach the final goal of the stock assessment, because the evaluation for the population level depends on accuracy of such parameters. On the basis of the past records on the land research as well as in the pelagic research, some parameters are estimated for the seal herd of Robben origin in this paper.

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The basic biological data which are used here for estimate of parameters are picked up mainly from the Reports on Fur Seal Investigations of the USSR 1958—1969.

Number of Pups Born

In the stock assessment of seals, an important parameter is the number of pups born at the breeding island. At Robben Island, the number of pups born used to be counted every year in the end of July or early in August just after the harem is broken naturally. Since only one large harem ground at Robben Island faces to the south-eastern beach, most of black pups on land can be counted per head except for some pups escaping from land to sea at the time of count. In 1960 and 1961, the counting was not carried out, but the pup production was estimated by 8.5% increment than the record in the previous year. Such an increasing ratio during these years seems to be reasonable in comparison with the rising trend of number of Pribilof pups in the past. In Table 1, the pup productions comprising the number of dead pups and living pups are indicated from 1955 through 1969.

Table 1. Number of pups born at Robben Island.

Year class	Number of pups born	Number of dead pups	Number of pups alive
1955	25,500	—	} Estimated by 8% decrease
1956	27,500	—	
1957	29,700	4,888	24,812
1958	32,200	3,407	28,793
1959	35,000	5,443	29,557
1960	38,000	3,899	34,010
1961	41,200	5,898	35,302
1962	44,700	6,543	38,157
1963	49,000	8,237	40,763
1964	51,400	9,200	42,200
1965	48,400	20,286	28,114
1966	44,900	1,493	43,407
1967	56,500	1,354	55,146
1968	45,800	8,740	37,050
1969	43,500	4,100	39,400

As another approach, the pup production can be estimated from the tag recovery. The tagging for pups carried on in late August and early in September, and subsequent tag recoveries in the commercial kill present an estimate of the number of pups alive at the time of tagging, because the tagging for the front flipper by monel metal is practised later than the counting. The pup production is estimated from the formula given by Chapman (1951) who modified Petersen method. Table 2 shows the number of pups alive estimated from tag recoveries in males of age 3 commercially killed at Robben Island. Pup estimate based on tag recoveries is usually higher than the count for living pups. According to calculation, lost tags in the period from the tagging to the commercial kill gives the overestimate for the pup production. The double tagging for one pup has been carried out

at Robben Island to examine the ratio of lost tag, however, the ratio unfortunately can not be calculated from the published record in the Reports on Fur Seal Investigations of the USSR. The lack of data makes it impossible to revise the pup production overestimated from tag recoveries in the Robben seal.

Table 2. Pup production estimated from tag recovery of age 3 males at Robben Island.

Year class	(n) Males killed	(t) Pups tagged	(s) Tagged males in kill	(N) Pup estimate	(c) Count for living pups
1959	3,080	9,015	587	47,242	29,557
1960	3,387	10,376	881	39,861	34,010
1961	4,320	10,472	1,196	37,806	35,302
1962	4,678	10,756	649	77,434	38,157
1963	4,199	11,295	763	62,084	40,763
1964	3,582	10,889	441	88,278	42,200
1965	1,341	8,004	393	27,266	28,114

$$N=\frac{(n+1)(t+1)}{S+1}$$

Table 3. Occurrence of tag lost by year class at Robben Island

Year class	Age of male 2	3	4	5	6
1959	0.311	0.375	0.417	0.304	0.391
1960	0.041	0.114	0.206	0.201	0.237
1961	—	0.039	0.168	0.145	0.335
1962	0.531	0.508	0.509	0.638	0.606
1963	0.370	0.344	0.424	0.418	0.080
1964	0.432	0.523	0.550	0.613	—
1965	—	—	0.380	—	—

If the loss of tags attached is a primary reason of the overestimate, known values for n, t, and c in Table 2 will present the reasonable number of tagged males in the commercial kill. There is a possibility to overlook lost tags in examining the tag recovery. Through the procedure of $[(n+1)(t+1)/c]-1$, revised s' is obtainable. The ratio of lost tag given by $(s'-s)/s'$ is shown in Table 3 for each year class. Estimated ratio varies greatly from year class to year class. The 1962 and 1964 year classes indicate higher ratio than the 1960 and 1961 classes, though the tagging method does not alter. In the generel statement, the loss ratio increases with the age of seals. In the Pribilof seals, the ratio of lost tag was examined from the return of double tagged seals. Roppel, Johnson and Chapman (1965) reports that the ratio of lost tag varies from 0.216 to 0.546 for ages 3—5 males of the 1958 year class. It is concluded that the ratio of lost tag is in the same order between the Robben seals and the Pribilof seals. Finally, there is no other biological basis available for estimating the number of pups born at Robben Island, except for the per head count.

Natural Mortality and Recruitment of Bull

On Robben Island, the number of dead bulls has been counted every year but no record on the age composition of dead bulls has been reported. For the purpose of insuring males in optimal numbers to enlarge the herd, the excess bulls were taken intentionally at Robben Island, however, the age composition of bulls taken of age 10 and above has not been reported. Therefore, no data is available for estimating the natural mortality rate of harem bulls or territorial bulls.

From data included in Table 4 which shows the age composition of males killed commercially at Robben Island from 1958 through 1969, it is possible to estimate the natural mortality rate of bulls of age 7 and above. When Heincke's method is applied to the actual kill of bulls except for the less kill in 1965, the mean rate of natural mortality is 0.32 for bulls of the Robben herd. From the age composition of excess bulls killed in 1960 and 1961 at Robben Island, Chapman (1964) estimates 0.34 as the natural mortality rate.

Table 4. Age composition of males killed commercially at Robben Island.

Year	Age of male											
	1	2	3	4	5	6	7	8	9	10	10+	Total
1958		89	1,386	858	566	89	41	42			56	3,127
1959	2	88	1,976	1,795	554	137	87	22			192	4,853
1960	1	124	2,116	1,670	645	391	463	356	166	94	184	6,210
1961	1	340	3,221	1,584	460	227	354	353	237	67	103	6,947
1962		480	3,080	1,711	496	214	273	306	231	74	172	7,037
1963		459	3,387	1,734	684	205	226	249	156	60	105	7,265
1964	3	1,032	4,320	1,852	379	52	73	166	162	50	123	8,212
1965		1,336	4,678	1,869	450	77	13	3	3	2	1	8,432
1966	5	2,238	4,199	1,598	557	130	110	157	113	46	26	9,179
1967		1,014	3,582	1,839	1119	594	255	141	121	74	19	8,758
1968	6	1,486	1,341	811	573	420	175	105	83	45	25	5,070
1969		1,833	3,360	575	242	93	34	28	18	7	31	6,221
Total	18	10,519	36,646	17,896	6,725	2,629	2,104	1,928	1,290	519	1,037	81,311

Using the complete age composition of territorial bulls of age 10 and above in the Pribilof seal, Johnson (1968) estimates 0.38 as the natural mortality rate by Chapman-Robson (1960) formula. Peterson (1965) observes the return of 18 marked territorial males to harem ground from 1961 to 1963 and states that the annual mortality rate is 0.33 for the Pribilof seal. It is reasonable to interprete that the natural mortality rate of seals will elevate with the increment of age. To estimate the recruitment of male to age 7, 0.32 is adopted here as the annual mortality rate of bulls in the Robben herd.

The number of harem bulls and idle bulls has been counted every year at Robben Island since 1960. The number of bulls counted every 5 days indicates that the maximum number is usually obtained on 25 June for both harem and idle bulls. As the results of bull count, whether or not the excess bull should be killed has been determined on Robben Island. All

bulls do not necessary land on the island at a time of breeding season. For the Pribilof seal, Chapman (1964) gives a reasonable suggestion that harem bulls spend about one quarter in June and July at sea, while idle bulls spend half their time on land and half at sea. His suggestion is deduced from the following procedure. According to observation by Bartholomew and Hoel (1953), 80% of female seals is in the water at any time during the breeding season, and hence number of adult females at sea was calculated when a total number of adult females is known. At sea, the proportion of bulls to adult females is examined from the pelagic research around the breeding island, therefore, finally the number of bulls at sea is estimated. Modifying the result obtained from the research records, Chapman reaches the above suggestion.

In the adjacent waters to Robben Island, there is no research record to estimate the number of bulls at sea during the breeding season, and hence Chapman's suggestion for the Pribilof seal is applied here to the Robben seal. The mean bull count at Robben Island from June through July enables us to estimate the total number of surviving bulls composed of harem and idle bulls from the following procedure. Estimate for the breeding season in 1962 is as follows.

Date of count		Bull count		
		Harem	Idle	Total
June	5	451	260	711
	10	766	410	1,176
	15	898	808	1,706
	20	954	1,445	2,399
	25	1,018	1,612	2,630
	30	848	1,482	2,330
July	5	782	1,245	2,027
	10	746	925	1,671
	15	651	926	1,577
	20	508	805	1,313
	25	438	805	1,243
Total		8,060	10,723	
Mean		733	975	

Total harem bulls estimated	$733\times 4/3 = 977$
Total idle bulls estimated	$975\times 2 = 1,950$
Total bulls estimated	2,927

From the same procedure for each season, the value, total bulls estimated/maximum bull count on 25 June, varies from 0.96 to 1.27 during 1960—1969. The mean value of 1.15, however, suggests that most of bulls land on Robben Island on 25 June.

Recruitment of bulls at age 7 is obtained from the next formula.

$$kB=(kB'-K)s+R$$

In transposition

$$R=k(B-B's)+Ks$$

Where

R ; Recruitment of male at age 7
B ; Bull count in a year
B' ; Bull count in the year before
K ; Kill of excess bull in the year before
s ; Annual survival rate of bull

Constant k is 1.15. K,B and B' are given in Tables 4 and 5. S is previously estimated as 0.68 in this chapter. From the above formula, an average recruitment is 1,331 bulls annually from 1960 through 1969. The recruitment of bulls indicates a declining trend from year to year, and 2,113 bulls in 1960 and 624 bulls in 1969. Since the recruitment of bulls is used for the estimate of male escapement at age 3, it is reasonable to take the mean recruitment of 1,154 bulls from 1962 through 1969 as shown in Table 6.

Table 5. Bull count made on 25 June at Robben Island.

Year	Harem	Idle	Total
1958	516	500	1,016
1959	666	700	1,360
1960	869	1,146	2,015
1961	935	1,490	2,425
1962	1,018	1,612	2,630
1963	1,056	1,409	2,465
1964	857	1,595	2,452
1965	741	1,472	2,213
1966	1,274	1,660	2,934
1967	1,189	1,250	2,439
1968	1,002	1,250	2,252
1969	754	1,250	2,004

Table 6. Male recruitment to age 7 and male escapement ratio at age 3.

Year	Actual kill (A)	Recruitment to age 7	Escapement at age 3 (B)	Escapement ratio B/A
1962	4,053	1,610	3,931	97.0%
1963	4,409	1,218	2,974	67.5
1964	4,489	1,282	3,130	69.7
1965	5,792	643	1,570	27.1
1966	5,610	1,950	4,761	84.9
1967	6,299	926	2,261	35.9
1968	7,799	976	2,383	30.6
1969	8,847	624	1,523	17.2
Mean	5,912	1,154	2,816	47.6

Another estimate can be made through more simple procedure. The bull count in Table 5 indicates that the number of bulls increased from 1958 to 1961 and was stable from 1962 to 1969, although there is a slight divergence in the trend of increment between harem

and idle bulls. An average bull count per year was 2,424 from 1962 through 1969. When the annual mortality rate of bulls is 0.32, 776 bulls are dead naturally a year On the other hand, a total of 4,061 excess bulls was intentionally killed from 1962 through 1969 to insuring males in optimal numbers, though the number of kill fluctuates from year to year. An average kill was 507 bulls a year. The sum of natural death and the intentional kill implies the average recruitment of males at age 7, and hence 1,283 bulls are recruited every year. Above two estimates of bull recruitment are in the same order.

Male Kill Adjusted to Age 3

Male seals killed commercially at Robben Island are composed of age 2 to age 6, while the commercial kill of male at Pribilof Islands comprises seals of ages 2—5. The ratio of age 2 male catch against the total commercial catch has increased recently at Robben Island, exceeding 30% in 1968 and 1969. The ratio of age 6 male catch against the total catch was 9.1% in 1968 and 1.5% in 1969, indicating 3.8% as a mean from 1958 through 1968. Ratios of ages 2 and 6 were higher, compared with those in the kill at the Pribilof and Commander Islands. Such age composition is characteristic in the kill at Robben Island.

As far as the annual survival rate from age 2 to age 6 males concerns, no information has been available for the Robben seal, therefore, the annual survival rate of 0.80 which was estimated from the Pribilof seal, is applied to the Robben seal. Whether or not such a survival rate is valid and the rate is constant through the life of bachelor should be evaluated in the future.

Male kill adjusted to age 3 for the 1956 year class of the Robben seal is calculated as follows.

Age of seal	Actual male kill	Male kill adjusted to age 3
2	89	$89\times0.8=$ 71
3	1,976	1,976
4	1,670	$1670/0.8=2,088$
5	460	$460/0.8^2=$ 719
6	214	$214/0.8^3=$ 420
Total	4,409	5,274

Through the same procedure, adjusted male kill for each year class are given in Table 7.

Male Escapement Ratio and Male Survival to Age 3

Throughout the breeding season, all of bachelor seals do not always land on islands and hence a part of them stays at sea. Some males arrive at the breeding island after the hunting season has gone and besides some seals escape from kill because they do not reach the size limit imposed on the land killing. Since these males escape from the commercial kill, Kenyon, Scheffer and Chapman (1954) examine the escapement in the Pribilof seal

herd.

A portion of the male survival to age 3 is commercially killed at ages 4, 5 and 6, and the final survival is recruited to the breeding reserve. In other words, the final male survival equals to the amount of recruitment of bulls. The amount of escapement at age 3 is calculated through the recruitment of bulls divided by s^4. Since the annual survival rate from age 3 through age 6 for males (s) is 0.80, the amount of escapement is obtained for each year class. The sum of the male kill adjusted to age 3 and the amount of escapement indicates the male survival to age 3. Thus, the estimate of the male survival at age 3 is given for each year class. The mean ratio of escapement against the male survival to age 3 is 29.1%. The ratio declines from 43.6% in the 1955 to 13.1% in the 1962 year class.

For the practical use, the ratio of escapement is shown in Table 6 against the actual male kill. When the amount of escapement is divided by the actual kill from a year class, the mean ratio is 47.6%. Chapman (1964) estimates the male escapement to be 40% of the total male kill for the Pribilof seal. When the male survival rate of the Robben herd is 0.85 and 0.90, the escapement ratio at age 3 is 40% and 30% respectively.

Table 7. Male survival to age 3 in the Robben seal.

Year class	Revised male escapement at age 3	Male kill adjusted to age 3	Male survival at age 3
1955	2,027	5,083	7,110
1956	2,205	5,274	7,479
1957	2,245	5,343	7,588
1958	2,896	6,630	9,526
1959	2,805	6,263	9,068
1960	3,150	7,044	10,194
1961	3,900	9,058	12,958
1962	4,424	10,070	14,494
1963	4,022	8,644	12,666
1964	3,437*	6,764*	10,201
1965	1,468**	2,871**	4,339

Multiplying the actual kill by 0.50 gives the revised male escapement at age 3.

* The actual kill of age 6 is excluded.

** The actual kill of ages 5 and 6 is excluded.

The difference of these ratios may result from the divergence of topographic conditions between Robben and Pribilof Islands. In Robben Island, two hauling grounds of limited area locate in the vicinity of the north-east point and of the south point. As harem areas have potentiality to enlarge, landing of bachelor seems to be restricted in Robben Island, compared with the situation in Commander and Pribilof Islands. Some parts of males which escape from the commercial kill at Robben Island may spend the summer season on rookeries in Kurile Islands until they grow into bulls. The escapement ratio of 50% is of practical use for the Robben seal. This implies that about a half of bachelors remains in sea and about a half is on land during the hunting season from June to July. Multiplying the actual kill for each year class by 0.50 gives the revised male escapement at age 3.

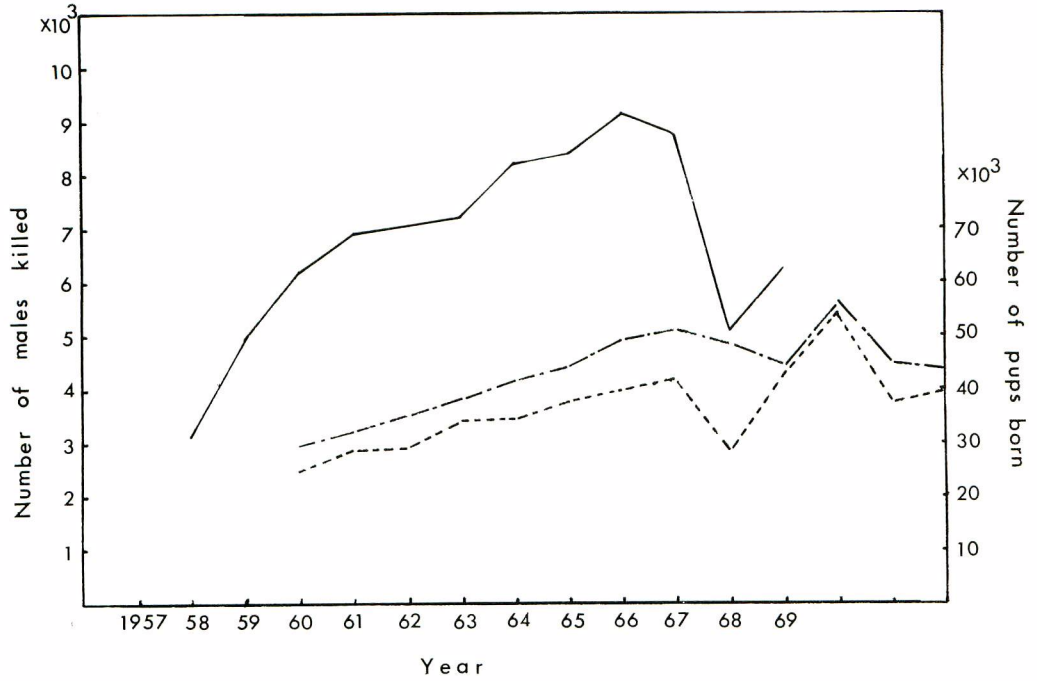

Fig. 1. Number of males killed and number of pups born at Robben Island
—— Male kill —·— Pups born ------ Pups alive

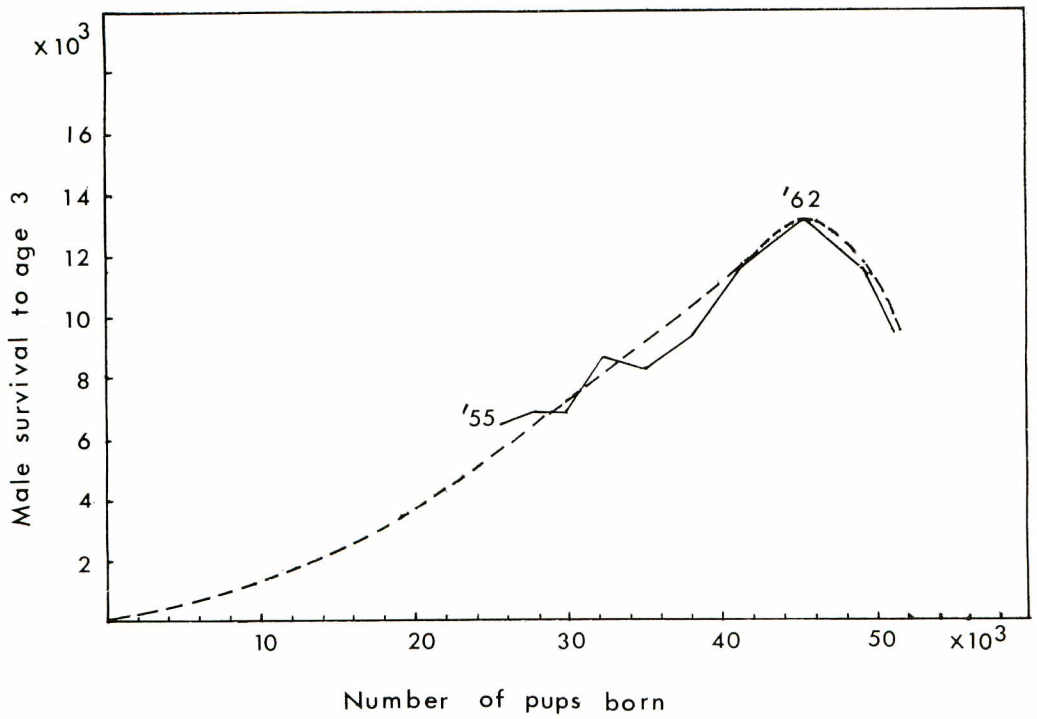

Fig. 2. Relationship of male survival to pup production in the Robben seal herd. Figure indicates the year class

Thus, revised male survival at age 3 is shown in Table 7 for each year class.

Number of males killed and number of pups born are plotted from year to year in Fig 1. The time scale for the number of pups born is translated 3 year to the right. The total male kill at Robben Island increased since 1958, with the peak in 1966. The extreme decrease of male kill in 1968 is probably affected by the fact that the amount of pups alive was abnormally small in 1965. It is a question that the male kill hereafter rises or fluctuates in spite of the increment of number of pups born. There was an increasing trend in the amount of pups born during past 11 years at Robben Island.

Fig. 2 shows the relationship between the number of pups born and the male survival at age 3 for each year class. In the 1962 year class, the male return around Robben Island reached the maximum level and afterwards declined. This reproduction curve indicates that the population of Robben seal exceeded the maximum sustainable yield in 1965. In the earlier year class than in 1955, no inrormation is available for completing the reproduction curve.

Natural Mortality Rate of Female and Pregnancy Rate

At Robben Island, no female kill has been intentionally carried out until 1969, and hence the natural mortality rate can be estimated from the age composition of females pelagically taken. Since the Sea of Japan is the main wintering waters of the Robben seal, the female age compositions recorded in the annual reports on Fur Seal Investigations of the USSR from 1960 through 1968 are summarized in Table 8. Most of 1,036 pelagic samples was obtained from 1961 through 1965 in the Sea of Japan, but the complete age composition is not available because the age determination is not made for seals over age 10. When Heincke's method is applied, the natural mortality rate is estimated to be 0.10 for females of age 8 and above. Estimate of the natural mortality rate is 0.11 for adult females of the Pribilof origin.

Table 8. Age composition of female seals collected in the Sea of Japan from 1960 through 1968.

Age	Frequeny
1	4
2	12
3	39
4	27
5	52
6	62
7	66
8	77
9	60
10	34
10+	603
Total	1,036

Table 9 indicates the age-specific pregnancy rate for female seals collected in the Sea of Japan from 1960 through 1968. Females of the Robben origin attain the sexual maturity at age 3. The apparent pregnancy rate is 79.1% in 932 samples of age 4 and above, which were taken almost in March, April and May. The pregnancy rate shows the highest level at age 10. It is necessary to examine the weighted pregnancy rate because the amount of young females is biased in the pelagic samples, however, the incomplete age composition in old females make the estimate of weighted pregnancy rate impossible. An approach to estimate is made in comparison with the pregnancy rate from the Pribilof seal. The age-specific pregnancy rate for samples

collected in the eastern Pacific is also shown in Table 9. The original data for the Pribilof seal are cited from the USA annual reports on Pelagic Fur Seal Investigations from 1960 to 1968 and rearranged for comparison with the Robben seal.

Females of the Pribilof origin attain sexual maturitv at age 4. This age of maturity is older by one year than in the Robben seal. The pregnancy rate for age 4 and above is 69.7% and that for age 5 and above is 77.2%. The apparent pregnancy rate obtained from pelagic samples is slightly higher in the Robben seal than in the Pribilof seal. Using the age distribution and applying the age-specific pregnancy rate obtained in the Pribilof female, Chapman (1961, 1964) estimates that the weighted pregnancy rate is 0.60 for the Pribilof herd. Here, it is possible to use only this value which is the minimum rate for the Robben population.

Table 9. Age-specific pregnancy rate, in the Robben and the Pribilof seal herds from 1960 through 1968.

	Robben origin				Pribilof origin			
Age	Nonpregnant	Pregnant	Total	Pregnancy rate	Nonpregnant	Pregnant	Total	Pregnancy rate
3	25	0	25	0.0	428	1	429	0.0
4	9	9	18	50.0	673	20	693	2.9
5	3	36	39	92.3	417	204	621	32.9
6	5	43	48	89.6	152	334	486	68.7
7	8	51	59	86.4	114	444	558	79.6
8	9	66	75	88.0	80	475	555	85.6
9	8	51	59	86.4	58	450	508	88.6
10	1	33	34	97.1	56	483	539	89.6
10+	152	448	600	74.7	538	2397	2935	81.7
Total*	195	737	932	79.1	2,088	4,807	6,895	69.7

Seals of the Robben origin collected in the Sea of Japan
Seals of the Pribilof origin collected in the eastern Pacific
* Total excludes female of age 3.

Age-specific pregnancy rate may be affected by the population level of seals. When pelagic samples are divided into two groups ; 1960—63 and 1964—68, the age-specific pregnancy rate is higher in the 1960—63 group than in the 1964—68 group. This is quite clear for each age of both the Robben and the Pribilof population. The reproductive mechanism bringing forth such a variation is complicated and not yet known. As far as the reproductive conditions concerns, it is reasonable to consider that the transition of population level is regulated by the change of maturity age and pregnancy rate.

Female Survival to Age 3

The fact that most of females conceive at age 4 in the Robben seal as indicated in Table 9, implies that most of females of age 4 and above lands on rookeries in the breeding season to conceive foetuses. Therefore, the number of females of age 4 and above is

estimated by using the pup production and pregnancy rate. In the case of no commercial kill of females, the female survival at age 3 in a year is calculated by the following formula.

$$\left(N_f+\frac{N}{P}\right)\ s=\frac{N''}{P}$$

Accordingly

$$N_f=\frac{1}{Ps}(N''-Ns)$$

Where

N_f ; Female survival to age 3 in a year
s ; Annual survival rate of adult females
P ; Weighted pregnancy rate
N'' ; Pup production in the following year
N ; Pup production in a year

S and P were estimated previously, and 0.90 and 0.60 for the Robben seal. By known N and N'' in Table 1, N_f is obtainable from year to year and shown in Table 10. In 1967 and 1968, N''-Ns indicates negative values and hence N_f is invalid. In both years, the pup production is lower than in the year before. The female suvival to age 3 becomes greater in s of 0.95 than in s of 0.90, in the case of the same pregnancy rate. In the case that s is 0.85, the result that the female survival to age 3 is larger than the pup production in three years before is not acceptable. On the other hand, the natural survival rate of adult females may be slightly lower than the value of 0.90, when the complete age composition of females is obtained. I believe the natural survival rate is very close to 0.90.

Table 10. Female survival to age 3 and ratio of female survival to male survival at age 3.

Year	Female survival	Ratio of famale survival to male survival
1958	11,148	1.57
1959	12,037	1.61
1960	12,963	1.71
1961	14,111	1.48
1962	16,241	1.79
1963	13,519	1.33
	Mean	1.58

It is well known that the female survival is better than the male one in the northern fur seals. Therefore, the relation between the male survival and female survival to age 3 is expressed as follows.

$$N_f=\lambda N_m$$

Where, N_m is the male survival to age 3 in the year. The coefficient λ is estimated as indicated in Table 10. During 1958—1963, when the size of the Robben population continued to grow, the mean value of λ is 1.58. Since 1964, the value fluctuates greatly and hence it is not available here. Compared with the value of λ which is estimated for the Pribilof herd (Chapman, 1961 and 1964.), 1.58 is a reasonable value. It is noticed that the value of λ ranges from 1.33 to 1.79 for the Robben seal.

Maximum Sustainable Yield

Three kinds of procedure were applied in the past to estimate maximum sustainable yield for seals of the Pribilof origin. Nagasaki (1961) applies Ricker's method to the relation between the amount of male harvest in ages 3—4 and the number of pups born. Ricker (1954) makes this model to explain mathematically the prey-predator relationship. Nagasaki estimates the maximal male harvest produced when the annual pup production is maintained at the optimum level. Considering that the probability of pup survival is proportional to the food intake of adult female, Chapman (1961) makes a model to interprete the relation between the male survival to age 3 and the pup production. Simultaneously, assuming that male return-rate varies linearly with pup production, Chapman proposed another logistic curve suitable for relationship between the male survival and the pup production. From two fitted curves, he estimated the maximum sustainable yield for both sexes of the Pribilof seal. North Pacific Fur Seal Commission Report from 1958 to 1961 (1964) summarizes concisely the backgrounds and procedures for three methods of calculation. Although three methods are independent with one another, there is a similar procedure among them, viz. Nagasaki and Chapman adopted model curves which satisfy the relation between the male kill or survival and the pup production, in order to estimate the maximum sustainable yield.

In this paper, another method is applied for estimation. With regard to female seals, a level of population is maintained when the recruitment and mortality is in a state of equilibrium. In other words, excess recruitment is permitted to be killed in order to keep a sustainable yield. In the Robben seal, females at age 3 are recruited to the adult population. The apparent pregnancy rate of the Robben female is 50.0% at age 4 and 92.3% at age 5, according to the records of pelagic researches in the Sea of Japan during 1960—68. These values are comparable with 2.9% at age 4 and 32.9% at age 5 for the Pribilof female seal during the same period.

The amount of females to be taken is determined by the following formula.

$$K_f = N_f - a\left(N'_f + \frac{N'}{P}\right)$$

$$= N_f - aN'_f - a\left(\frac{N'}{P}\right)$$

Where

K_f ; Number of females to be killed
N_f ; Female survival to age 3 in a year
N'_f ; Female survival to age 3 in the year before
N' ; Pup production in the year before
a ; Annual mortality rate of adult females
P ; Weighted pregnancy rate

N_f and N'_f have been estimated already. N' can be counted at Robben Island. Known a and P are 0.10 and 0.60 respectively. Therefore, K_f is obtainable from year to

year. Since the weighted pregnancy rate probably is higher for the Robben seal herd than for the Pribilof seal herd, trial calculations were practised in the case that P is 0,65 and 0,70 respectively. In the above equation, the female survival to age 3 minus the female annual mortality of age 3 and above indicates the excess females to be killed.

The total kill to be permitted comprises both the female kill and the male kill, as follows.

$$K_t = K_f + K_m$$

Where

K_t ; Total kill

K_m ; Actual male kill

In any population level, it is possible to produce the sustainable yield K_t, and hence the maximum sustainable yield for both sexes is obtained when K_t is maximal. Since K_f and K_m are known, the relation of K_t to number of pups born is shown in Fig 3. The total kill reaches the maximum level in less pup production than the male kill does. When 45,000 pups are born at Robben Island, the maximum sustainable yield of 14,000 seals is produced, comprising 8,000 females and 6,000 males. Higher rate of pregnancy brings less

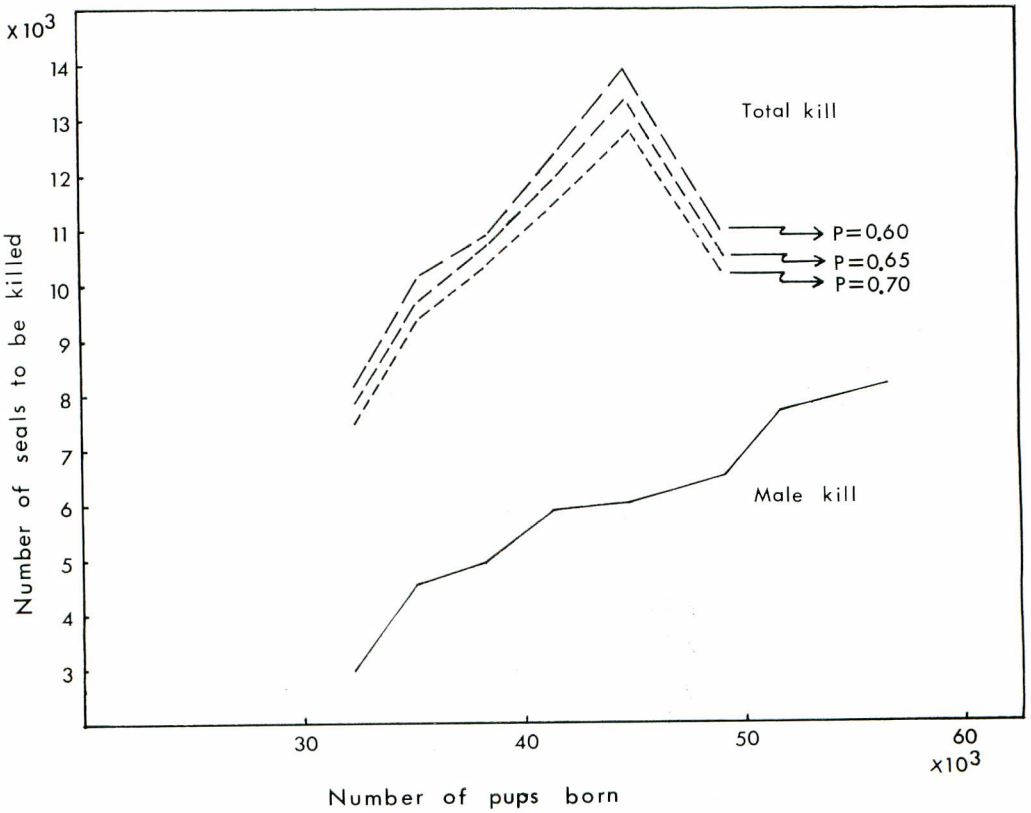

Fig. 3. Sustainable yield in the Robben seal herd. Total kill includes male and female catch. P indicates weighted pregnancy rate

yield. For example, when the annual mortality rate for the adult female is 0.10 and the pregnancy rate is 0.70, the maximum sustainable yield of 13,000 is composed of 7,000 females and 6,000 males. Fig. 3 shows the total kill in the case that the weighted pregnancy rate is assumed as 0.60, 0.65 and 0.70 respectively. There is no priori reason that the male kill always exceeds the female kill in the population of fur seals. The survival rate of females is higher than that of males in the northern fur seals. The male escapement and the efficiency of pup production in the Robben herd is greater than those in the Pribilof herd.

Conclusion

On the basis of biological statistics collected in the land and pelagic researches on fur seals until 1969, the stock assessment of the Robben seal was made. The Robben seal exceeded the population level to produce the maximum sustainable yield and it is now in the stage of level-off. To maintain the maximum sustainable yield, the excess of females should be intentionally killed. Estimated values of basic biological parameters which is necessary to calculate the maximum sustainable yield are as follows, for the Robben seal herd.

1. The natural mortality rate of males from age 2 to age 7 is 0.20 per year.
2. The natural mortality rate of bulls of age 7 and above is 0.32 per year.
3. The natural mortality rate of adult females of age 3 and above is 0.10 per year.
4. At age 3, the male escapement ratio aginst the actual male kill is 50%.
5. The weighted pregnancy rate in females of age 4 and above is 0.60.

The maximum sustainable yield of the Robben seal is produced at 45,000 pup production, and it comprises 8,000 females and 6,000 males.

It is necessary to estimate the accurate value for each parameter through reexamining the past records and biological material. In particular, the accuracy of the age-spccific mortality rate for both sexes and the pregnancy rate should be confirmed in the future research. Since values of these parameters are affected by the size of population through the mechanism of self-regulation, it is urgent now to advance concretely the program of the future researches including the pelagic research. The relationship between the Robben seal and seals of Kurile Islands should be pursued furthermore.

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ロベン系オットセイ群の最大持続生産

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要　旨

北太平洋のオットセイ（*Callorhinus ursinus*）には，繁殖地をプリビロフ諸島，コマンダー諸島，ロベン島に依存する主要な3つの系統群が存在する。このうちのロベン系群では，商業捕獲の対象を若い独身雄獣にしぼり雌獣の保護をはかった結果，資源は過去10数年にわたり増大し続けた。しかし，近年に至って，生まれる仔獣類の増加にもかかわらず，独身獣の帰島数が減少する傾向が現われ，密度依存効果が問題となっている。

本論文においては，生まれる仔獣数，雄成獣の計数値，陸上調査および海上調査よりえられた年級別捕獲年令組成などの基礎統計資料をもとにして，いくつかの資源パラメータの推定を行なった。雄については，3才で捕獲をまぬがれるエスケープメントの割合および繁殖島に対する3才での回帰数，成獣の自然死亡率ならびに加入量を推定した。また，雌については，成獣の妊娠率および自然死亡率を推定した。これらをよりどころとして，3才までの雌雄生残率の割合ならびに3才時の雌加入量を求め，持続生産を維持しながら捕獲できる雌獣数および最大持続生産量を推定した。

ロベン系オットセイ群では，生まれる仔獣数45,000頭のときに雄6,000頭，雌8,000頭の最大持続生産がえられる。したがって，現在の資源水準は，過剰なメスを間引ける段階にあると指摘できる。各パラメータについては，過去に求められたプリビロフ系群からえられたものと対比して，ロベン系群の特長をとらえてある。